GROUP 12

CYBER S.H.I.E.L.D.

Final Presentation

MEET THE TEAM

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BACKGROUND & MOTIVATION

- Evolution of Power Systems
- Grid modernization caused by expansion of renewables and shift towards a connected and decentralized grid
- Goal is to create an evolved grid that is:
  - Flexible to integrate distributed energy resources (DER)
  - Accommodate two-way flow of electricity and information for power management
  - Provide protection against physical risks and cyber risks
- Higher risk for cyber attacks unless proper security is built in
  - Crucial for engineers to develop an algorithm to detect cyber attacks

- CYBER S.H.I.E.L.D. is a physical testbench of a cyber attack detection and prevention algorithm and an educational outlet for the evolution of electric power systems

GOALS

Goal Type	Description
Basic	Create a model smart home with a functioning Energy Management System. A touch screen used to interact with the model. This serves as an educational experience to demonstrate knowledge on power systems.
Advanced	Model smart home implemented and updated to account for a hybrid solar system. Simulated cyber attacks are employed on the model smart home and attack detection and mitigation algorithms are tested.
Stretch	Model smart home completed with hybrid solar system and educational touch screen. Loads are categorized into three levels of priority: low, medium, high.

OBJECTIVES

- The model home must use a hybrid solar system
  - Solar panel will provide energy to the loads in the model smart home
  - Battery used for energy storage
  - Multiple loads demonstrate that the system is functioning correctly
  - Energy management system (EMS) used to distribute and store energy
- Data collected from meters are sent to the OPAL-RT in the Digital Grid Lab
  - This data will be used to employ multiple forms of cyber attacks
  - If attack is detected, appropriate measures are taken for the event to be isolated
- A digital touch screen will be utilized to encourage interaction with the project
  - Users will be able to select areas of the model to see the voltage, current, state of charge (SoC), and power absorption or supply

ENGINEERING SPECIFICATIONS

TOUCH SCREEN

Touch Screen & Touch Screen Platform			
Parameter	**Specification**	**Engineering Requirement**	**Marketing Require-ment**
Dimension	34.06" x 56" x 34.75"	The touch screen platform must be the appropriate size for the weight, length, and width of the screen	11, 12
Weight	At Most 100 lbs	The weight of the touch screen must be suitable for transportation	11, 12
Touch Screen Response Time	At Most 5 Seconds	Once a setting has been selected on the touchscreen, the model must reflect that selection of a source or load within five seconds	7
Number of Touch Points	At Least 2	The touchscreen should be multi touch capable and the total number of touch points should be at least 2	7
Number of Touch Points	At Least 2	The touchscreen should be multi touch capable and the total number of touch points should be at least 2	7
Number of Available Measurements	At Least 7	Must display V, I, P, and SoC measurements of sources on the touch screen	1
Communication with Model	Wired Communication with USB	The model must be able to accurately communicate source measurements to be displayed on the touch screen	5
User Interface Capability	Allows Selection of AC and DC Loads, AC and DC Sources	UI Will Allow Selection of DC and AC loads depending on PV panel and battery SoC; UI Will Allow Selection of Sources (DC or AC)	8, 7
Response to Cyber Attack Detection	Shows Warning on Touch Screen	Following the launch of a cyber attack on the OPAL-RT, the touch screen should send an alert and indicate if attack was detected	2
Accuracy of Metered Data	90% Accurate	Data collected by PCB and AC meter must match the realistic V and I measurements and be displayed on touch screen	5

ENGINEERING SPECIFICATIONS

SMART HOME MODEL

Smart Home Model

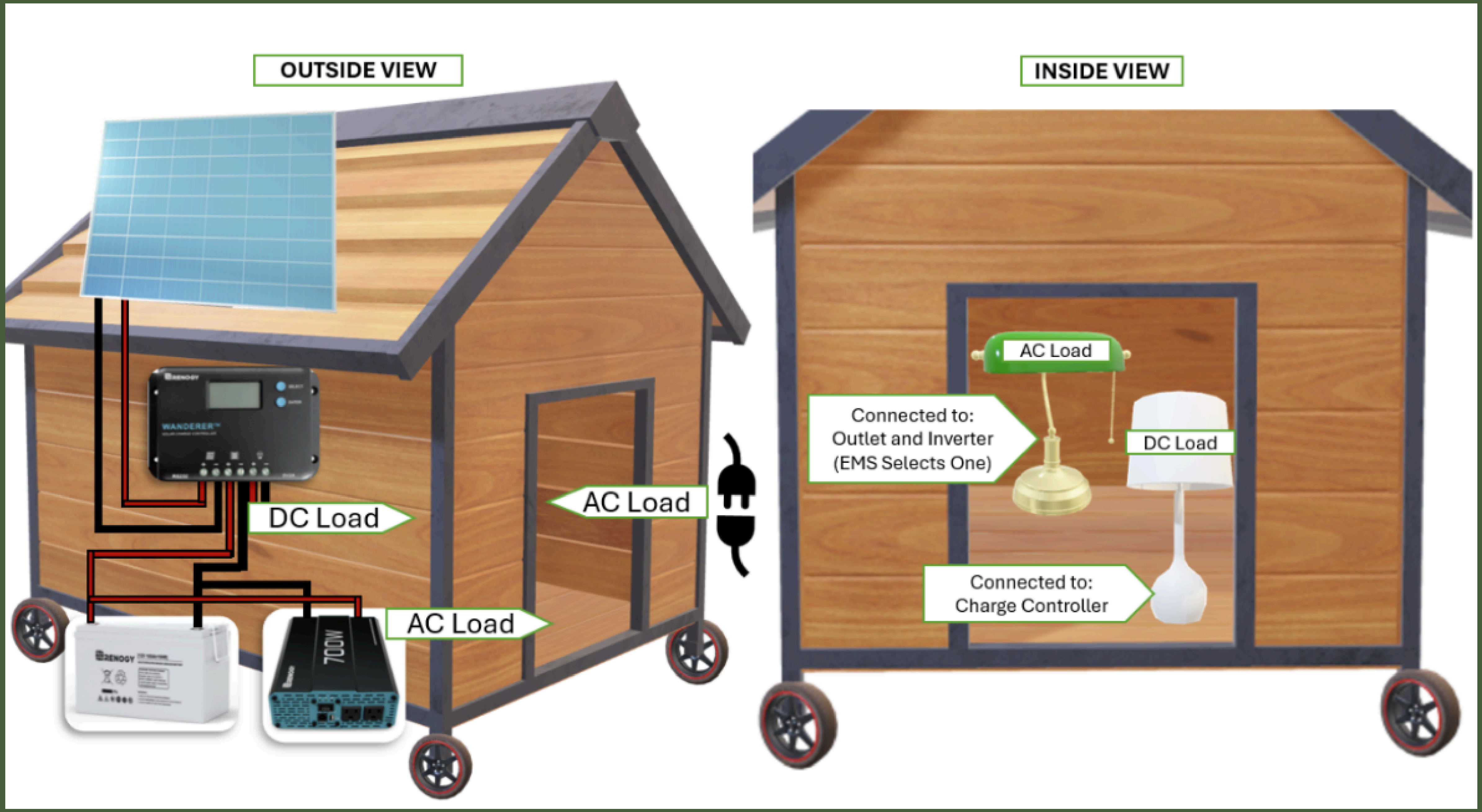
Parameter	Specification	Engineering Requirement	Marketing Require-ment
Dimension	34” x 34.5” x 83”	The smart home model must be the appropriate size to support the weight, length, and width of the PV Panel, Battery, and Inverter	11, 12
Weight	Up to 300 lbs	The weight of the model must be suitable for transportation	11, 12
Battery Voltage	12V	Battery must meet requirements of PV and supply loads when PV is not producing	9
Battery Capacity	100Ah	Battery must meet the current requirements of the PV panel	9
Battery Lifespan	At Least 5 Years	Battery must function successfully for at least five years	9
PV Panel Voltage	12V	PV panel must meet the voltage requirements of the system and provide power to AC/DC loads	9
PV Panel Power	100W	PV panel must meet the power requirements of the system and provide power to AC/DC loads	9
Relay Module Operating Voltage	12V	Relays must meet the voltage requirements of the system and enable connection or disconnection of sources/loads	3
Relay Module Maximum Current	10A	Relays must meet the current requirements of the system and enable connection or disconnection of sources/loads	3
Relay Toggling Accuracy	Equivalent or Above 95% Accurate	Relays must function with over 95% accuracy to switch on and off; Selection of sources and loads	3, 8
Inverter Voltage	12V	Inverter must meet voltage requirements of the system and convert DC/AC	3, 6
Inverter Output Power	At Least 100W	Inverter must meet the power requirements of the system and convert DC/AC	3, 6
Charge Controller Voltage	12V	Charge controller must meet the voltage requirements of the system and allow safe connection from the PV panel to the battery	3, 9
Charge Controller Current	10A	Charge controller must meet the current requirements of the system and allow for connection from the PV panel to the battery	3, 9

ENGINEERING SPECIFICATIONS
SMART HOME MODEL

Source Types	DC and AC	DC (solar, battery), AC (wall outlet connection, inverter output from battery)	8
Load Types	DC and AC	There must be both DC and AC loads (each having low, medium, and high priority)	6, 8
Load Power Consumption	100W	The system must meet load power consumption requirements to function properly	9
MPU	Capable of connecting to Touch Screen and OPAL-RT	MPU Must Receive Data from meters and Communicate with OPAL-RT/Touchscreen	4, 5
Energy Management System	Allow for Appropriate Selection DC, AC Source	EMS must intelligently select the appropriate source and loads for the state of the system	3

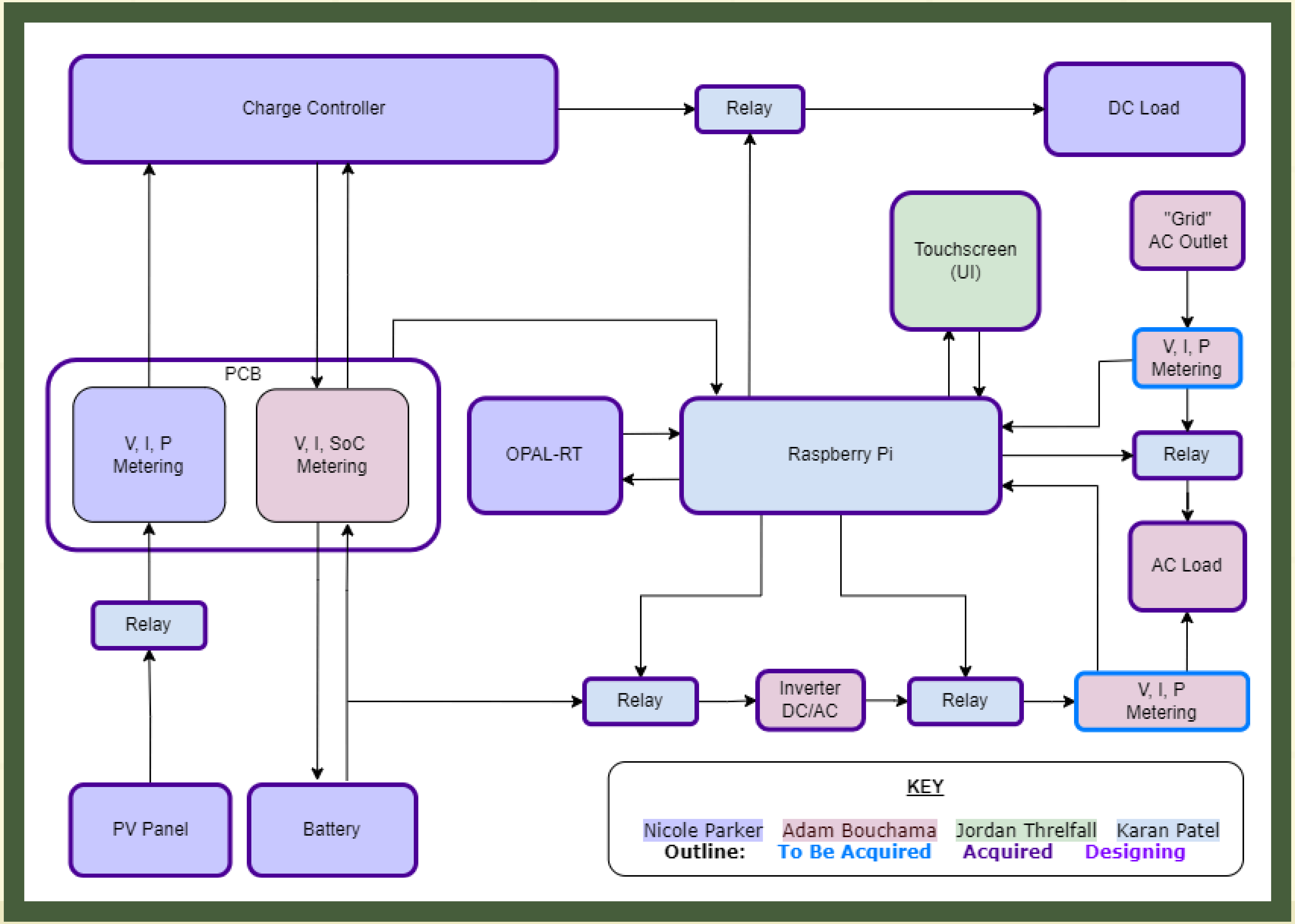
Communication with OPAL-RT	Voltage, Current Measurements Sent to OPAL-RT	Measurements collected in the model must be communicated with the OPAL-RT	4, 5
Source Measurements	Voltage, Current, SoC Measurements	There must be a collection of V, I, and SoC measurements from solar, battery, AC connection; this is sent to MPU	5
Load Measurements	Voltage, Current Measurements	There must be a collection of V and I measurements from DC loads and AC loads and this is send to MPU	5
Metering Accuracy	Equivalent or Above 95% Accurate	Sources and loads measurements must be accurate to reflect real time system conditions	4

THE MODEL SMART HOME



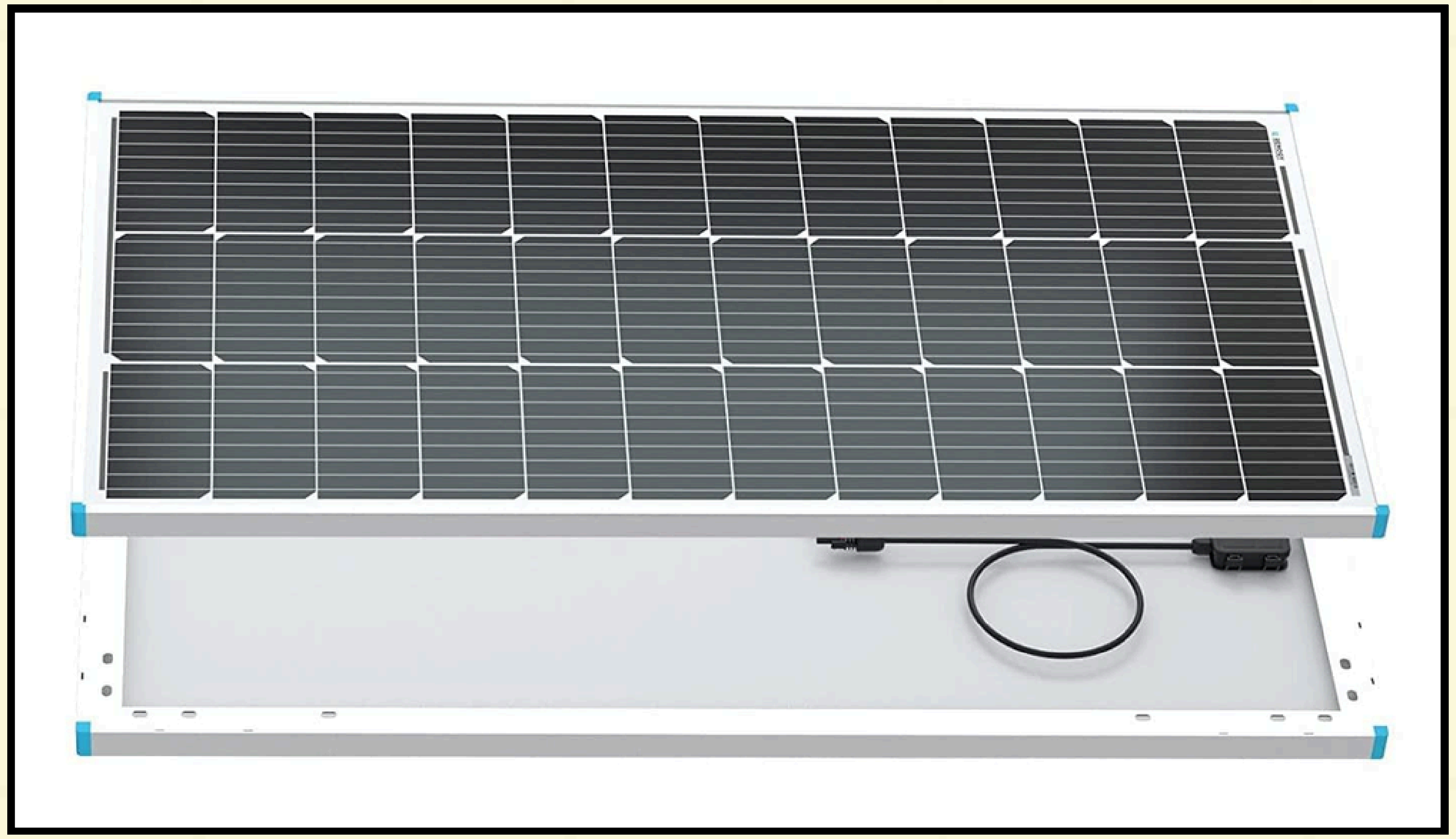
THE MODEL SMART HOME

HARDWARE BLOCK DIAGRAM



PV PANEL SELECTION

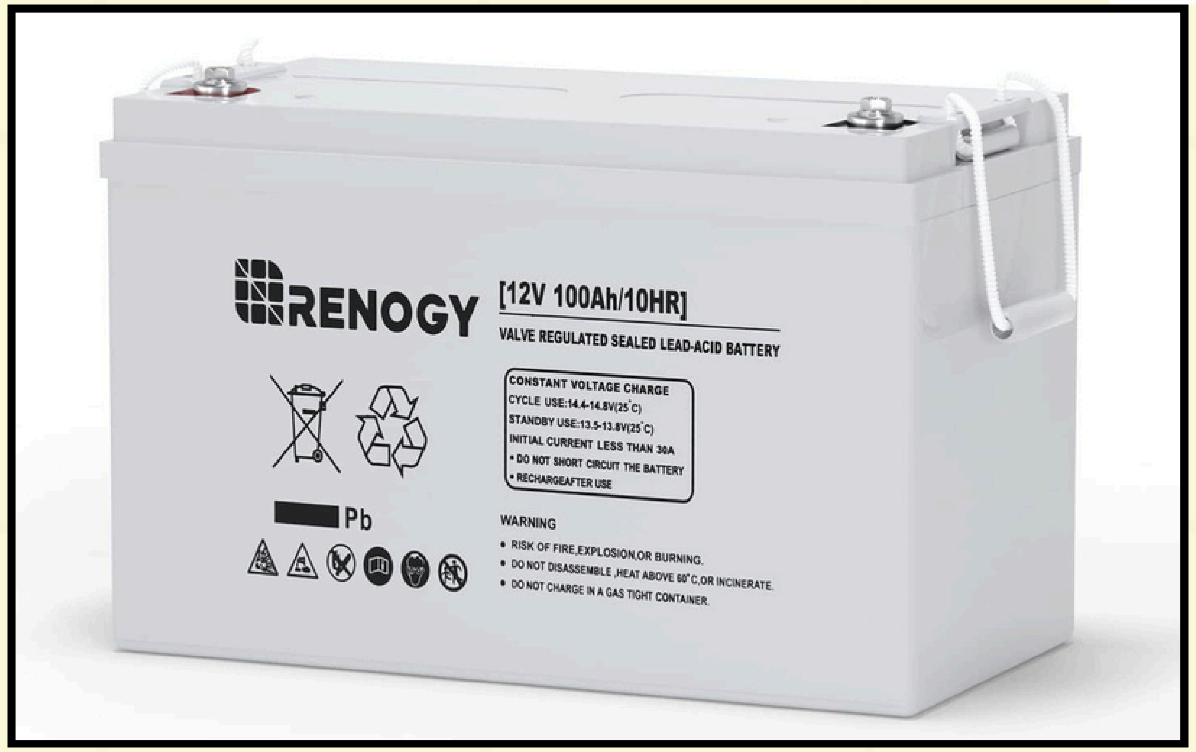
	Specifications	
Parameters	**Renogy**	**MEGA**
Price	$104.99	$109.99
Dimensions	41.8 x 20.9 x 1.38 in	58.7 x 13.8 x 1.2 in
Max Power Output	100W	100W
Optimum Operating Voltage	20.4V	19.5V
Optimum Operating Current	4.91A	5.13A
Open-Circuit Voltage	24.3V	22.8V
Weight	14.1 lbs	12.6 lbs



After completing this comparison, our team selected the Renogy 100W 12V Monocrystalline Solar Panel as it was less expensive and had the specifications that we needed to meet for the project. It was found to be the most durable and efficient option.

BATTERY SELECTION

	Specifications		
Parameters	**Renogy (Sealed)**	**WEIZE (Sealed)**	**Mighty Max (Gel)**
Cost	$189.99	$219.99	$199.99
Nominal Voltage	12V	12V	12V
Self-Discharge	(77°F/25°C): < 3% / month	(77°F/20°C): < 3.3%/ month	(77°F/25°C): < 3% / month
Rated Capacity	100Ah	100Ah	100Ah
Dimensions	13.1 x 6.9 x 8.6 in	12.99 x 6.73 x 8.43 in	12.10 x 6.65 x 8.47 in
Weight	63.9 lbs	63.0 lbs	59.22 lbs
Max Discharging Current	1100A	1150A	1100A
Standard Operation Temperature	77°F±9°F	77°F	77°F



Our Team Selected the Renogy Deep Cycle AGM Battery 12 Volt 100Ah because it was the most cost effective option out of the batteries selected. Due to this, we decided to go with the Renogy Sealed Lead Acid Battery as it met all the specifications we were looking for and was listed at a reasonable price.

INVERTER SELECTION

	Specifications		
Parameters	**Cotek**	**Renogy**	**Schumacher**
Price	$175.00	$119.99	$169.99
Surge Output P	250W	1400W	2000W
Continuous Output P	200W	700W	1000W
Output Frequency	50/60 Hz	60 Hz	60 Hz
Output Waveform	Pure Sine Wave	Pure Sine Wave	Modified Sine Wave
Efficiency	89%	90%	90%
Operating Temperature	-4°F - 140°F	-4°F - 158°F	-4°F - 150°F
Operating Vin	12 VDC	12 VDC	10.5 - 15.5 VDC

Our Team Selected the Renogy 700W 12V Pure Sine Wave Inverter It was the most cost effective option and it allowed for the second highest power output for the AC loads.

CHARGE CONTROLLER SELECTION

Parameters	Cotek	Renogy	Schumacher
Price	$175.00	$119.99	$169.99
Surge Output P	250W	1400W	2000W
Continuous Output P	200W	700W	1000W
Output Frequency	50/60 Hz	60 Hz	60 Hz
Output Waveform	Pure Sine Wave	Pure Sine Wave	Modified Sine Wave
Efficiency	89%	90%	90%
Operating Temperature	-4°F - 140°F	-4°F - 158°F	-4°F - 150°F
Operating Vin	12 VDC	12 VDC	10.5 - 15.5 VDC

After comparing the two charge controllers, our team selected the Renogy Wanderer PWM 10A Charge Controller as it was the most affordable and met all of the requirements of our project. This charge controller could be easily integrated with our solar panel since they are both Renogy products and designed to be used together.

TOUCH SCREEN SELECTION

Specifications	Samsung PM49H	Phillips 55BDL4051T	LG 49TA3E- B TA3
Price	$2,387.23	$1,678.00	$1,910.71
Dimensions	43.2 x 24.8 x 1.2 in	50.04 x 29.20 x 3.60 in	45 x 26.5 x 2.8 in
Screen	LED, HD, BLU	-	FHD IPS
Available Connections	HDMI 2.0, HDCP 2.2, USB 2.0	DP 1.2, USB, HDMI, VGA, DVI-D	HDMI, USB, DVI-D
Processor	Quad Core Cortex - A12 1.3GHz	Quad Core Cortex - A9 1.8GHz	-
Response Time	8ms	12ms	12ms
Storage	4.25GB Available	16GB	-
Weight	29.04 lbs	39.68 lbs	49.2 lbs
Power Consumption	47 W/h	76 W/h	60W/h

The Phillips touchscreen met all of the requirements we were looking for at a lower cost. Due to this, we decided to select this touchscreen for our project.

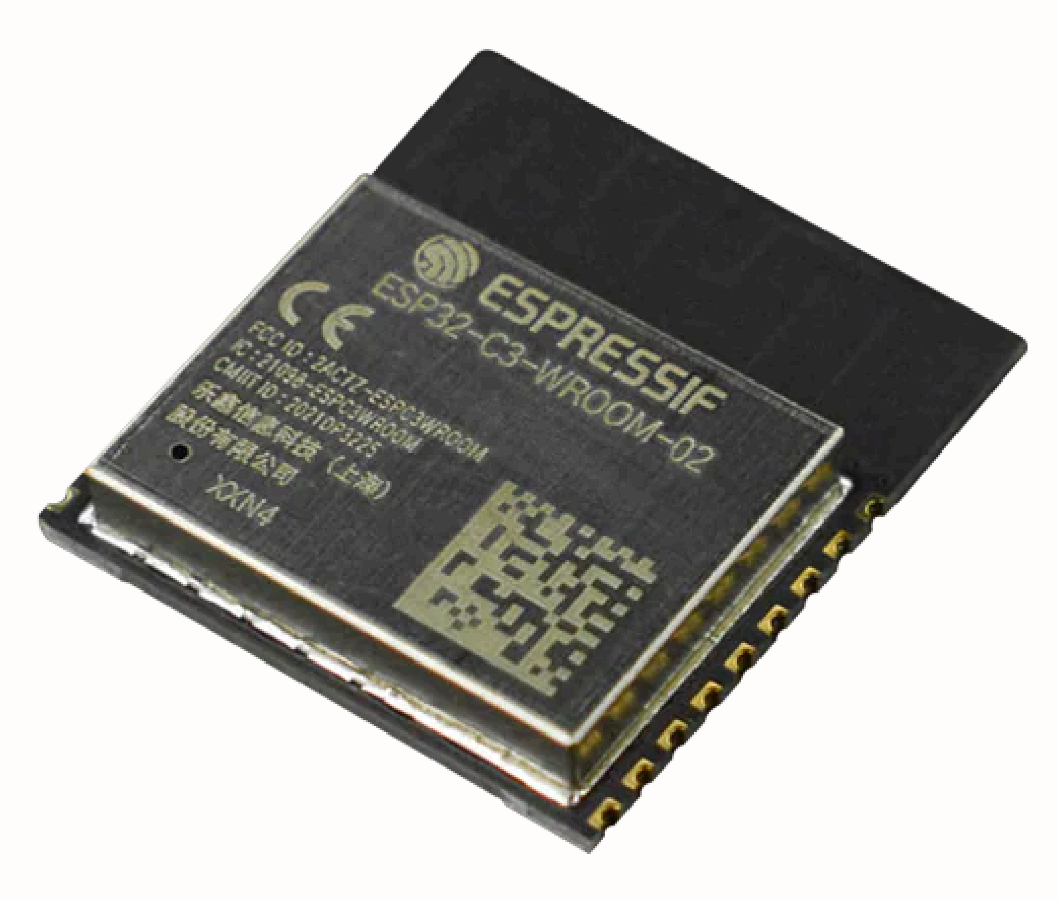
RELAY SELECTION

Specification	YQSIYU Solid State Relay 25DD	HiLetgo 12V 8 Channel Relay	Tongling Channel 12V Relay
Price	$9.99	$11.29	$16.70
Number of Relays	1	8	4
Maximum Load (AC)	N/A	AC 250V/10A	AC 250V/10A
Maximum Load (DC)	DC5 - 220V	DC 30V/10A	DC 28V/10A
Trigger Current	2mA	5mA	1.5mA
Module Voltage	N/A	12V	3V-30V
Module Size	2.55*1.88*1.29 in	55.7 * 1.97* 0.73 in	3.35 * 2.76 * 0.79 in

After comparing all three options, we decided to go with the YQSIYU Solid State Relay. We chose this option because it was able to meet all the requirements of our project in order to successfully control the sources and the loads in the smart home.

MCU SELECTION

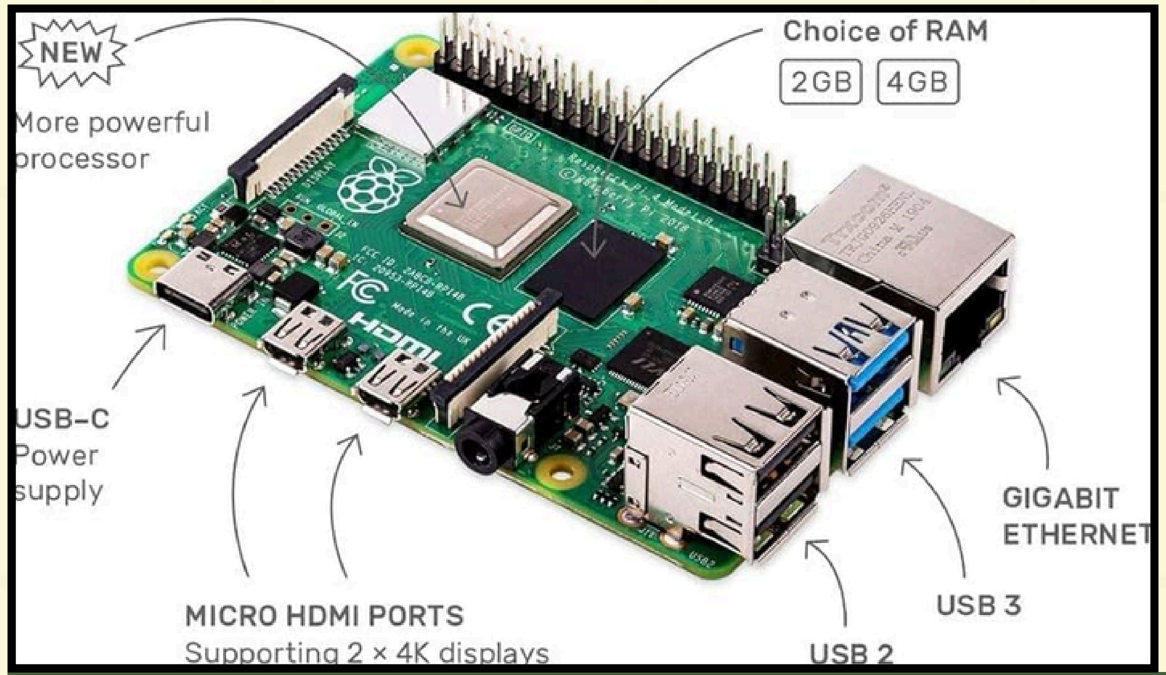
	Specifications		
Parameters	**ATmega328**	**MSP430FR6989**	**ESP32-C3**
Cost	~$2.63	~$10.77	~$1.90
Supply Voltage	1.8V ~ 5.5V	1.8V ~ 3.6V	3V ~ 3.6V
GPIO Pins	23	83	13
ADC Resolution	10-bit	12-bit	12-bit
Clock Speed	20MHz	16MHz	2.412 ~ 2.484GHz
Built-in WiFi/Bluetooth	No	No	Yes
Serial Protocol	UART, I2C, SPI	UART, I2C, SPI	UART, I2C, SPI
Memory	32KB	128KB	4MB
Power Consumption	Low	Low	High



After completing research on these microcontrollers, we decided to choose the ESP32-C3. Specifically the ESP32-C3-WROOM model as it is widely available and has more features while being inexpensive.

MPU SELECTION

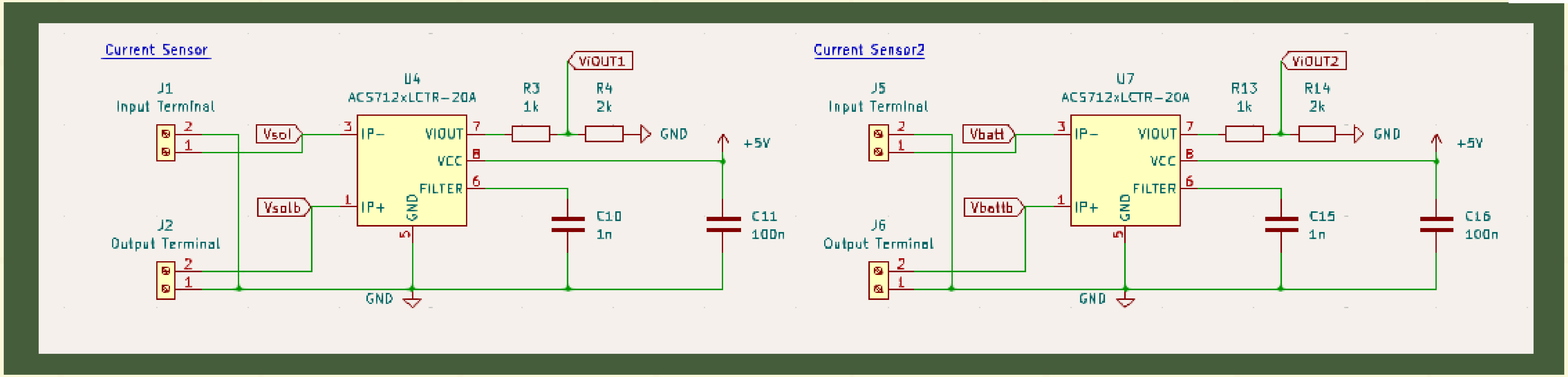
	Specifications		
Parameters	**Arduino Uno R3**	**Arduino Portenta H7**	**Raspberry Pi 4**
Cost	~$60	~$150	~$40
Processing Power	Very low	Low	High
Memory	2KB SRAM	8MB SDRAM	4GB LPDDR4
Storage	No external storage available	SD card slot (through the expansion port)	MicroSD card slot
Built-in WiFi/Bluetooth	No	Yes	Yes
Built-in Ethernet Port	No	No	Yes
Operating System	No	No	Raspberry Pi OS

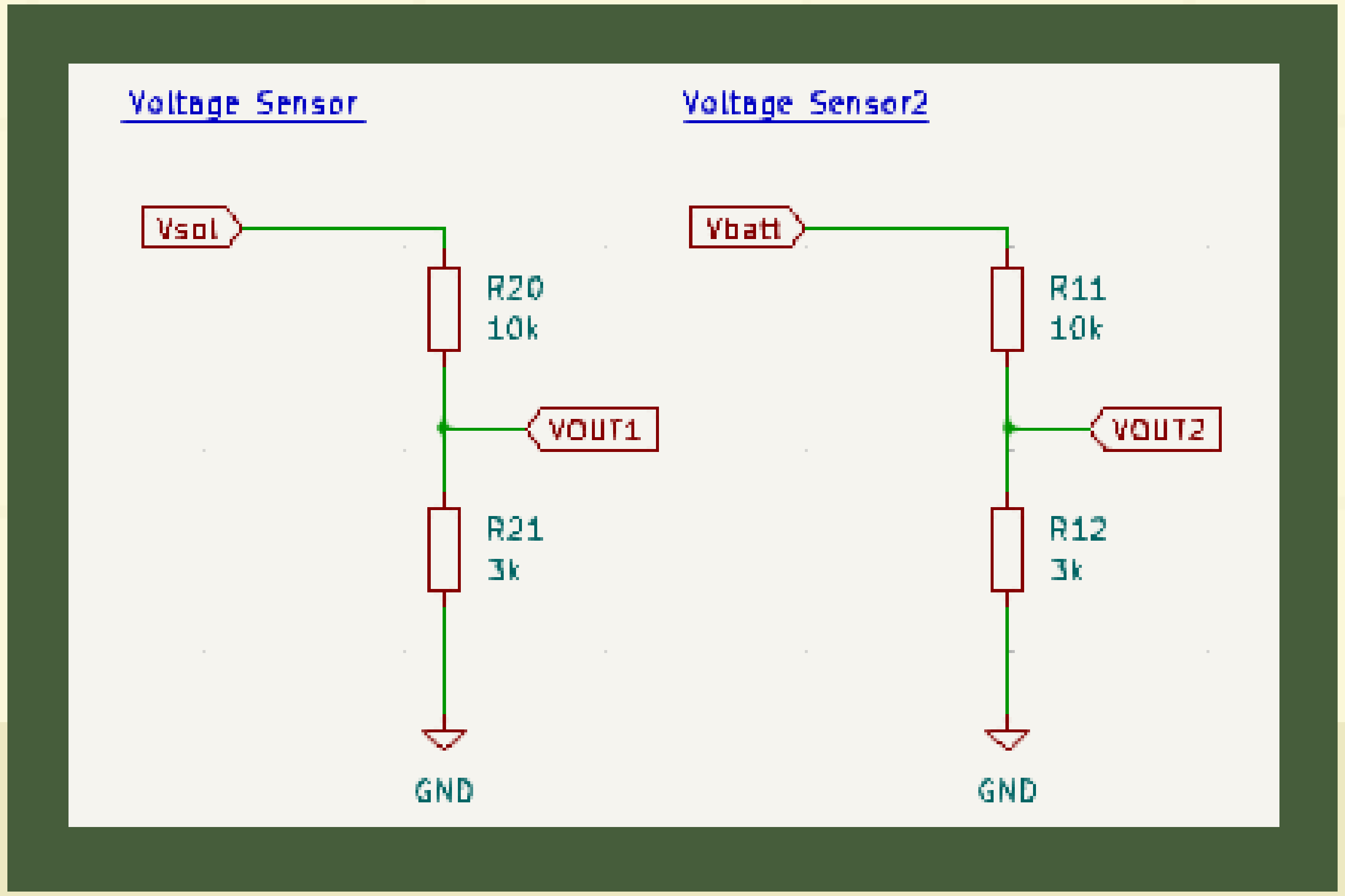


After thorough deliberation, we have chosen the Raspberry Pi 4: Model B as our base hardware. This decision stems from its stellar reputation for ease of implementation and the robust operating system it offers. Additionally, it boasts the necessary capability to meet the power requirements, efficiently driving the 5V needed to send signals to the relays

SCHEMATIC

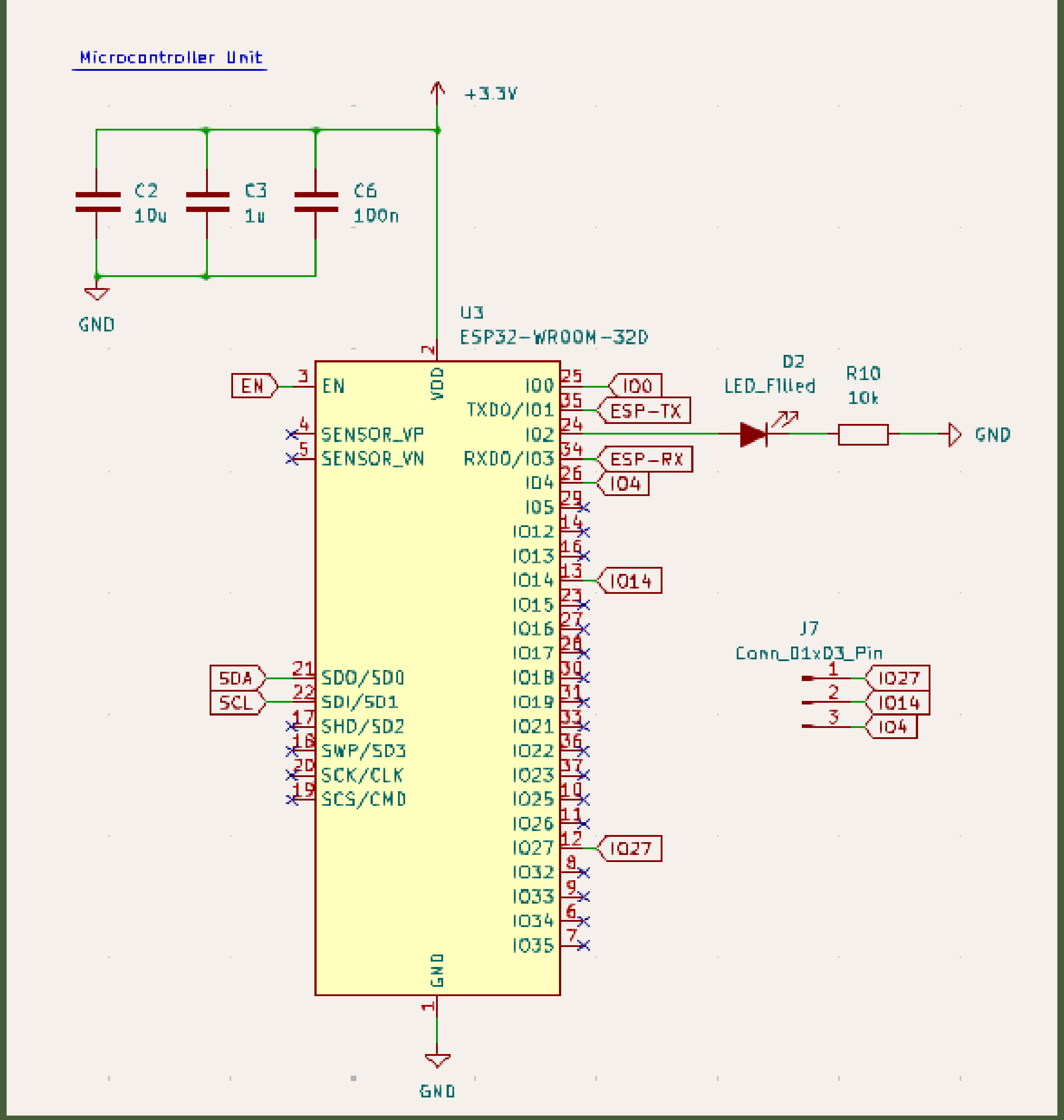
FOR PV & BATTERY METERING

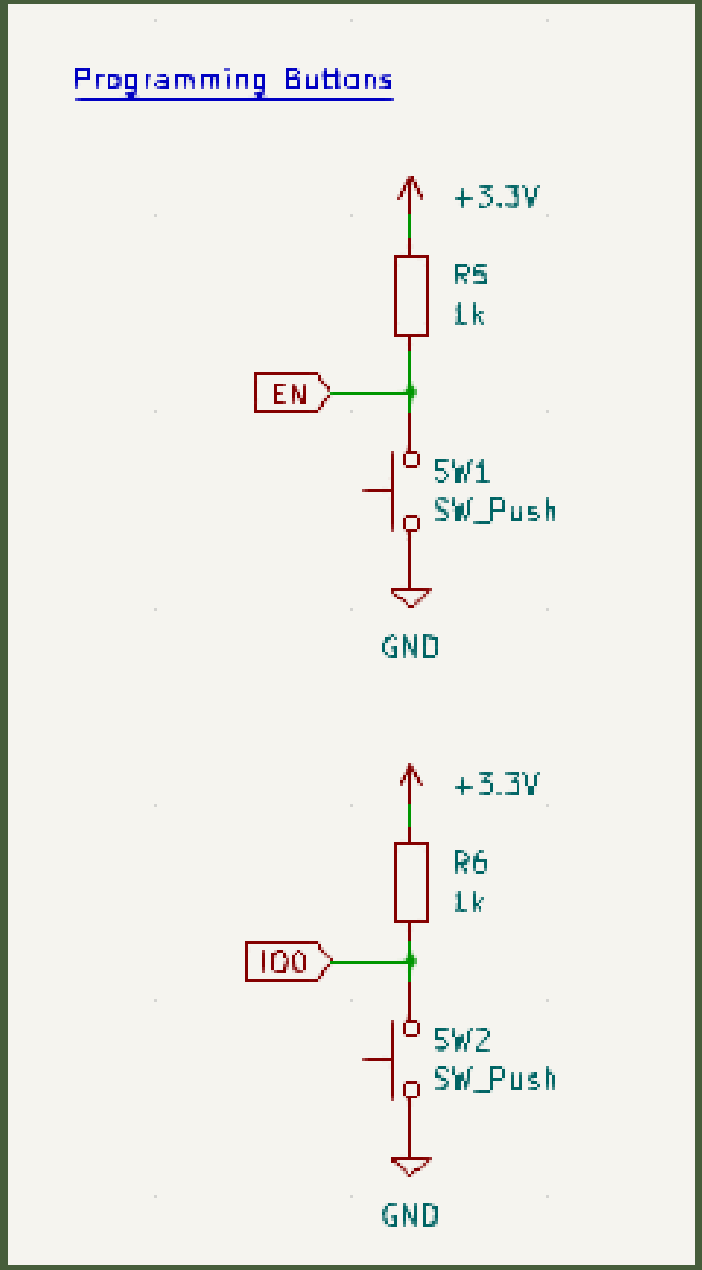


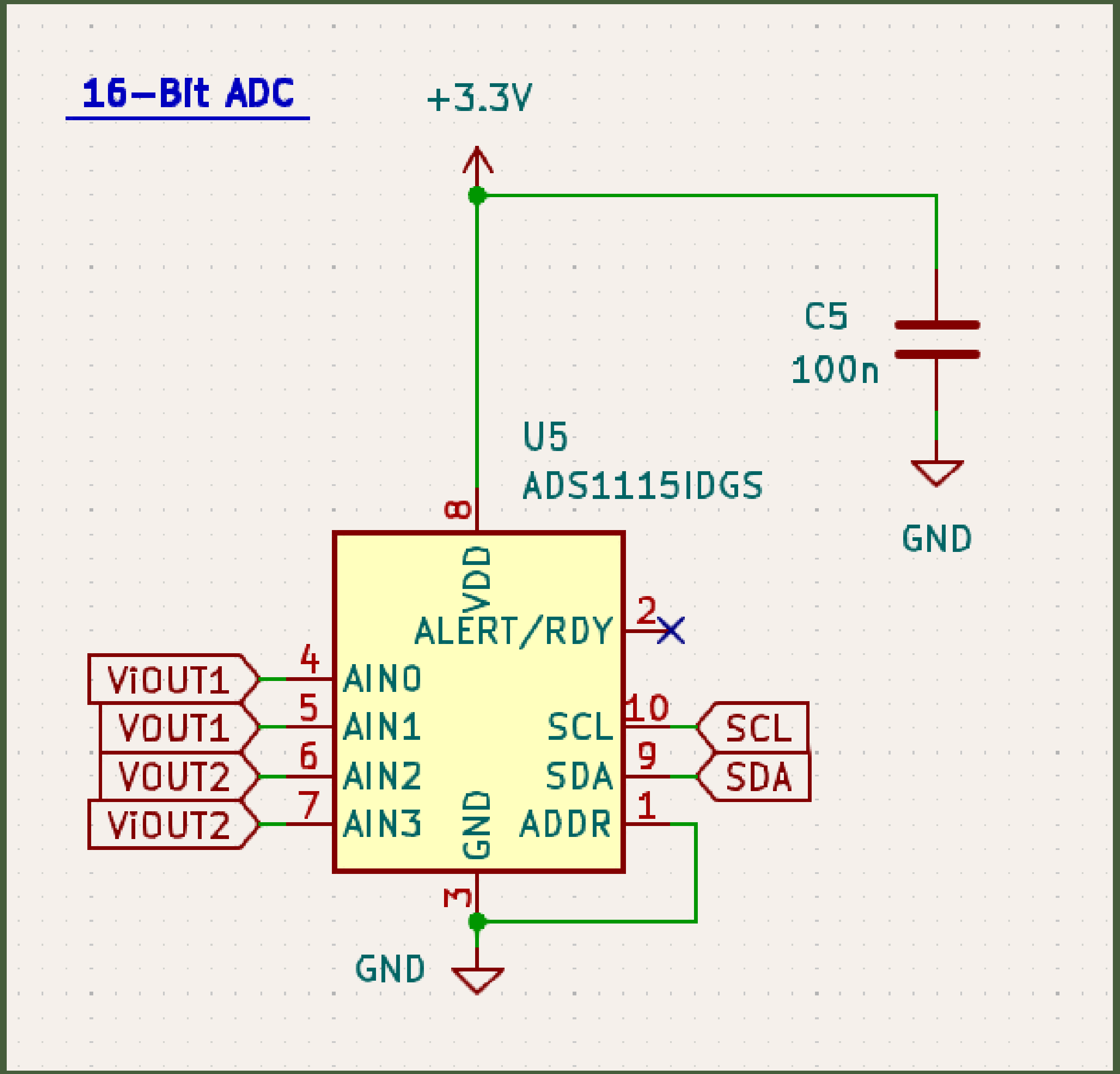


SCHEMATIC

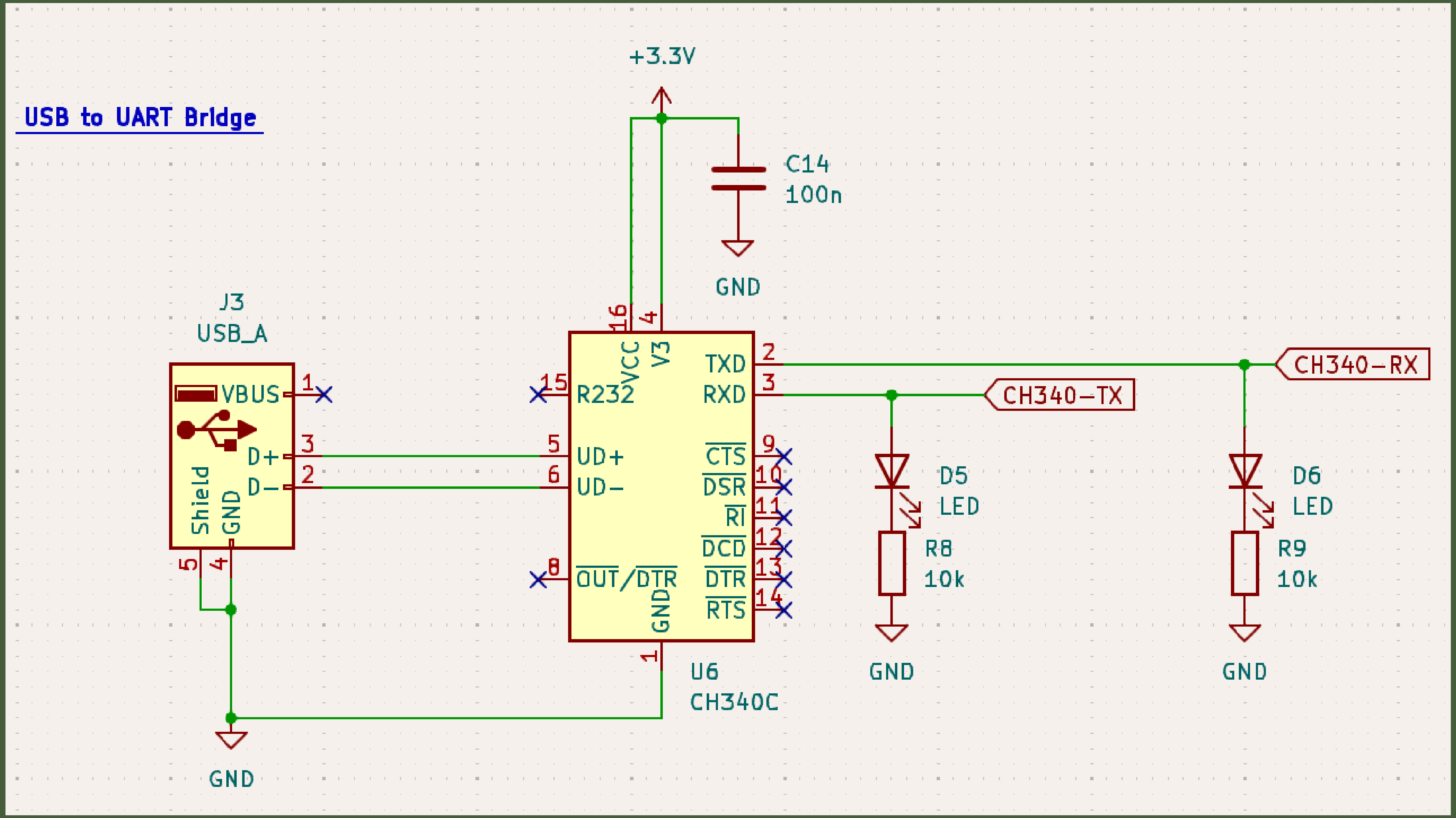
FOR PV & BATTERY METERING







SCHEMATIC
FOR PV & BATTERY METERING



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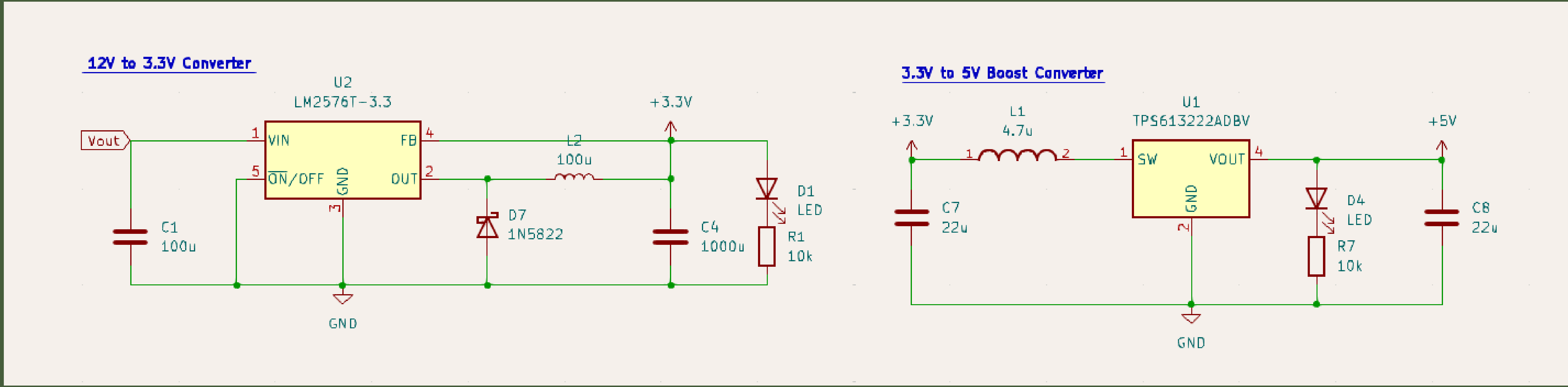
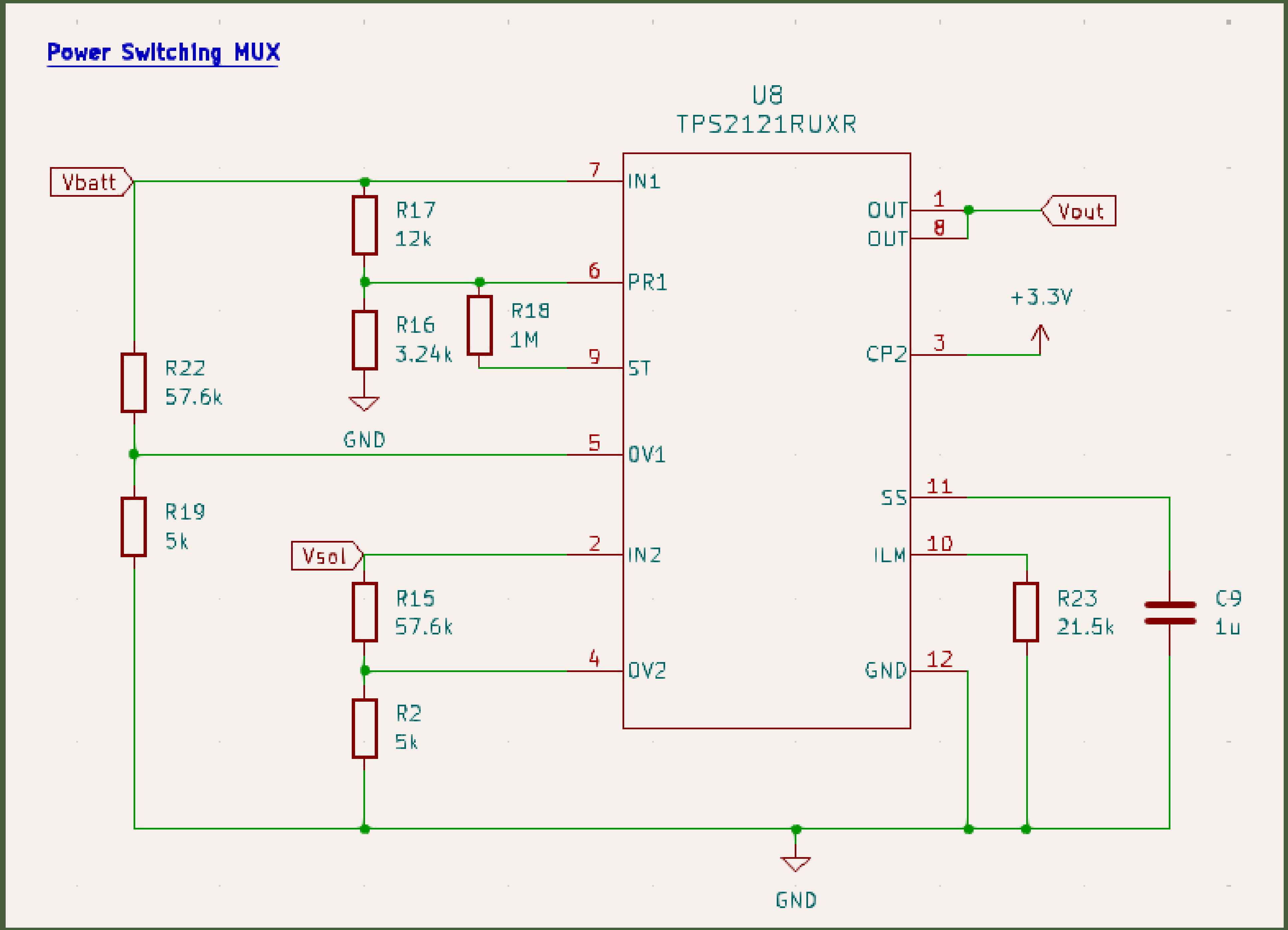
FOR PV & BATTERY METERING



SCHEMATIC

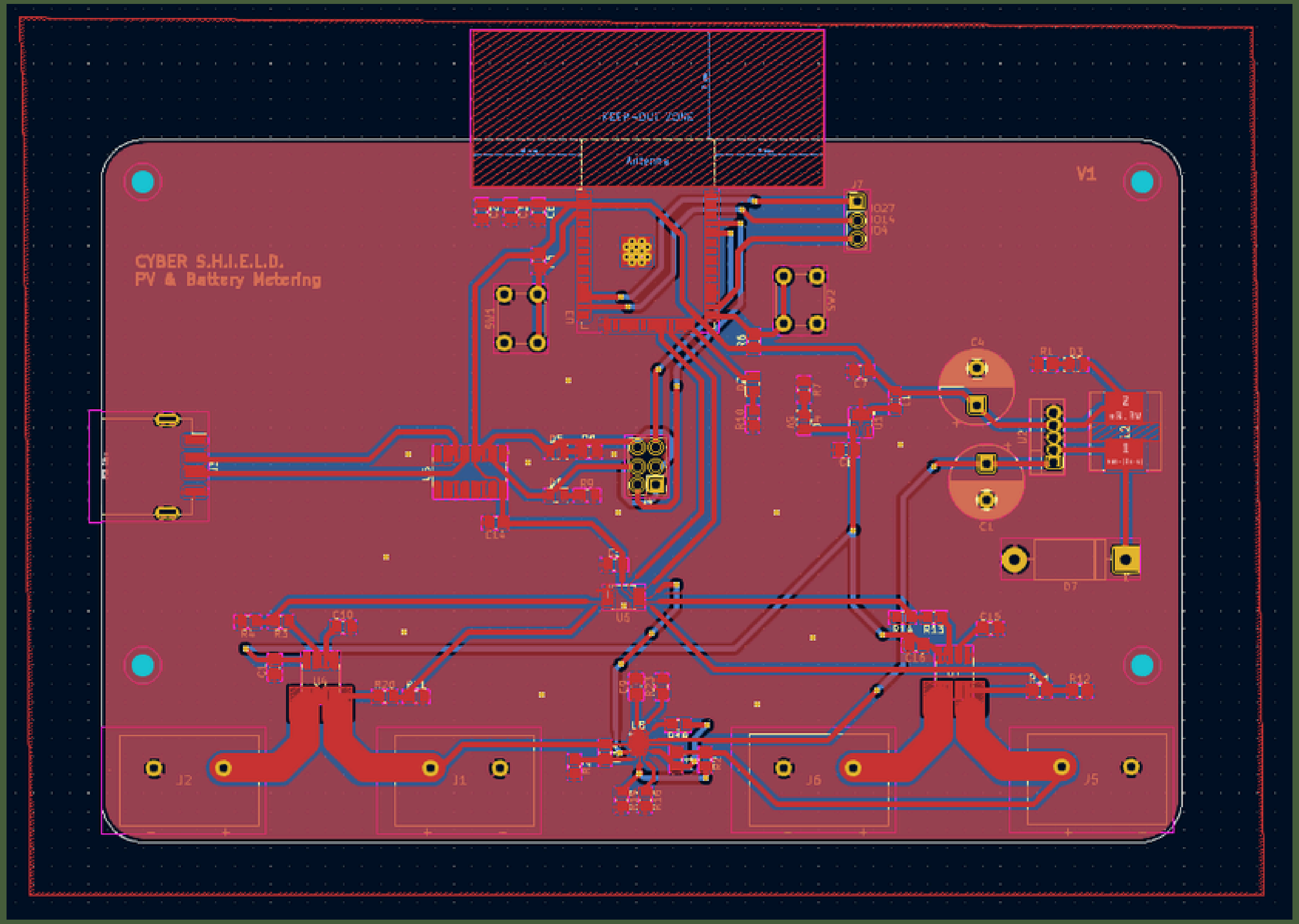
FOR PV & BATTERY METERING

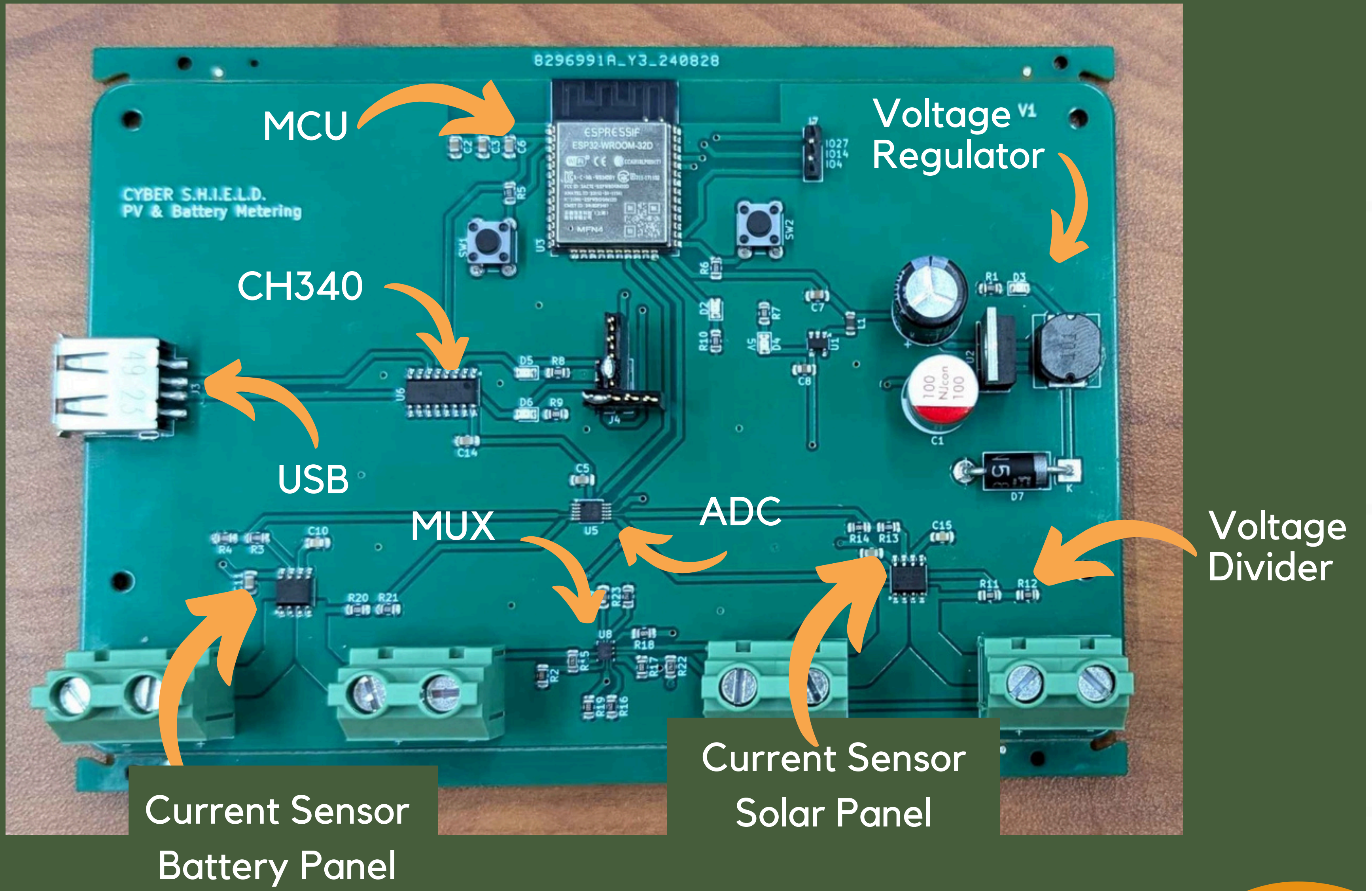


POWER DISTRIBUTION TABLE

Component	Quantity	Voltage (V)	Current (mA)	Power Consumption (mW)	Total Power (mW)
ESP32-WROOM-32E	1	3.3	23	75.9	75.9
ACS712xLCTR-20A	2	5	10	50	100
ADS1115	1	3.3	0.15	0.495	0.495
CH340C	1	3.3	7	23.1	23.1

PRINTED CIRCUIT BOARD
FOR PV & BATTERY METERING

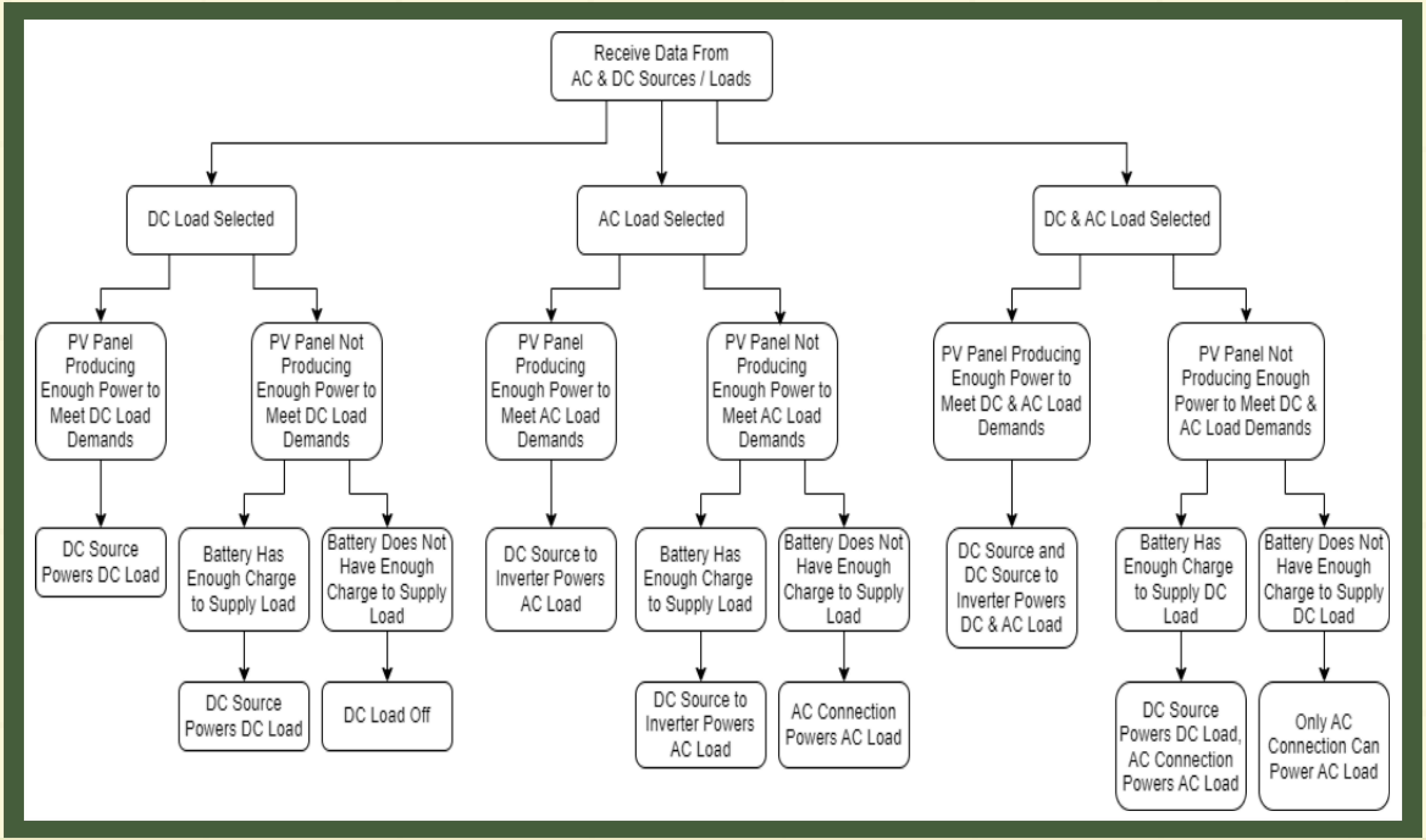




COMMUNICATION PROTOCOLS

Protocol	Pins/Interface	Speed/Range	Use Case
GPIO	40 pins	N/A	Relays
Wi-Fi	Built-in (802.11ac)	433Mbps ~100 meters	Raspberry Pi / UI Application
Bluetooth	Built-in (Bluetooth 5)	Up to 2Mbps ~10 meters	Remote Communication
I2C	SDA.SCL	Up to 400 kbps	Communication between SBC
UART	TX,RX	Up to 115200 bps	Communication between SBC
SPI	MISO, MOSI, SCLK, SS	Up to 10 Mbps	Communication between SBC
OpenDNP3	TCP/IP	Up to 100 Mbps	Raspberry Pi / OPAL-RT

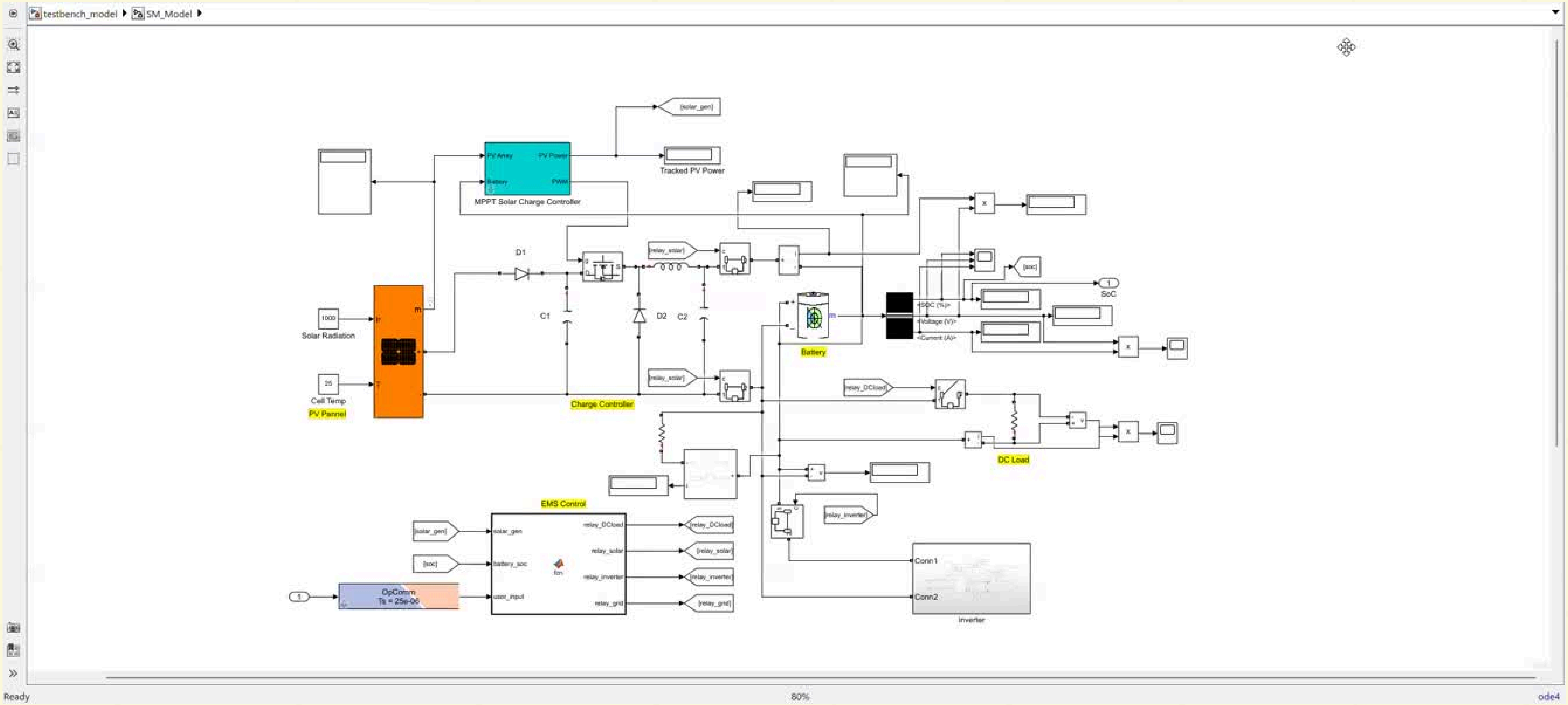
ENERGY MANAGEMENT SYSTEM



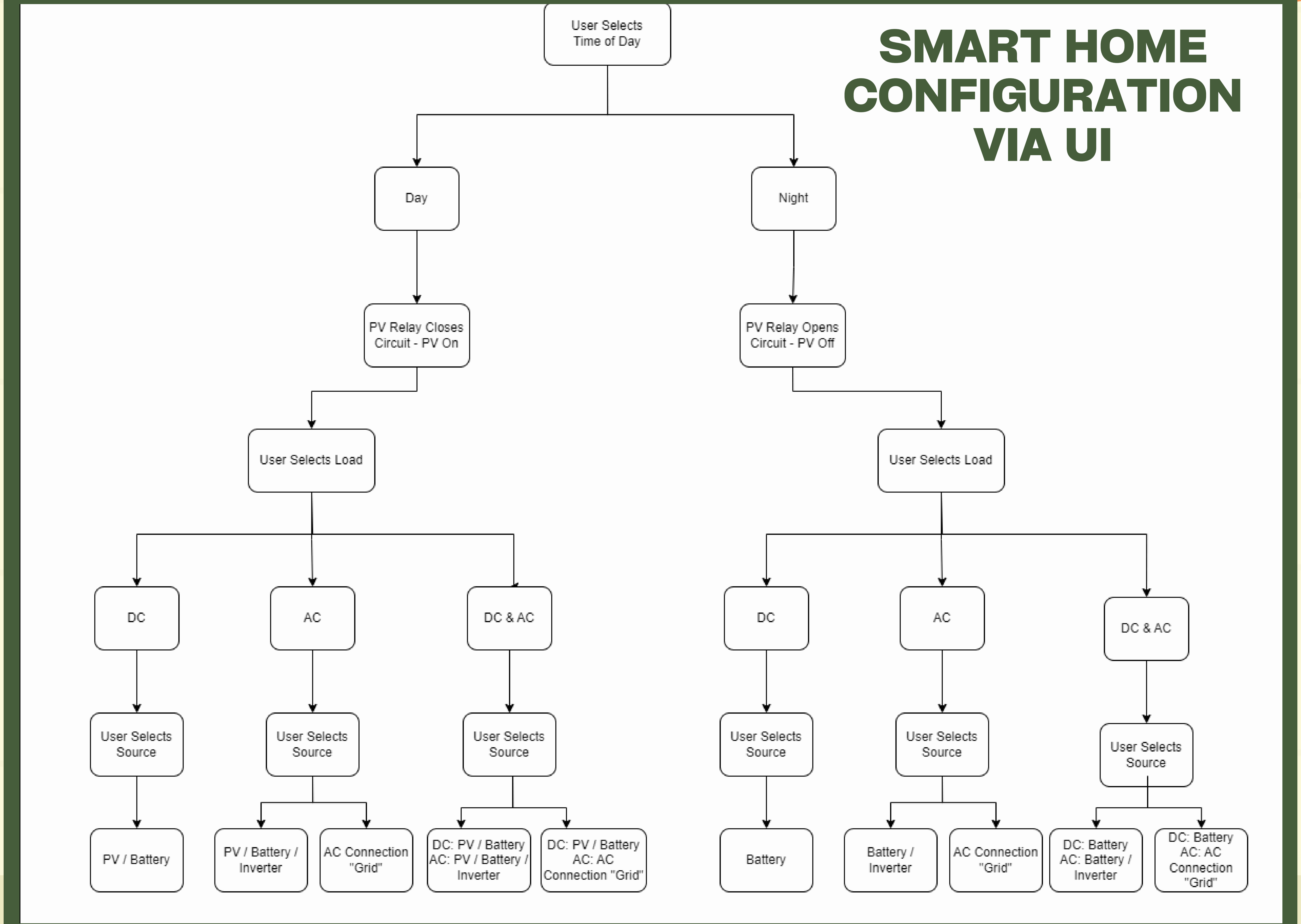
OPAL-RT INTEGRATION

- OPAL-RT TECHNOLOGIES is a leader in the development of PC/FPGA based simulators that run in real time, hardware-in-the-loop testing equipment, and rapid control prototyping system
    - Provides engineers with simulation technology that is able to test equipment in power systems and electro-mechanical systems
- Our project utilizes the OPAL-RT to run a simulated power system in real time
    - The measurements collected from the PCB are inputted into the simulation
    - When a cyber attack is launched on the simulator, an alert is sent to the Raspberry Pi
- DNP3 Communication is used to transfer that data across from the Raspberry Pi 4 to the OPAL-RT Simulation.
- Our system has been modeled in RT-Lab and can be seen on the next slide

OPAL-RT INTEGRATION



SOFTWARE FLOWCHART



SMART HOME CONFIGURATION VIA UI

SOFTWARE FLOWCHART

SMART HOME CONFIGURATION
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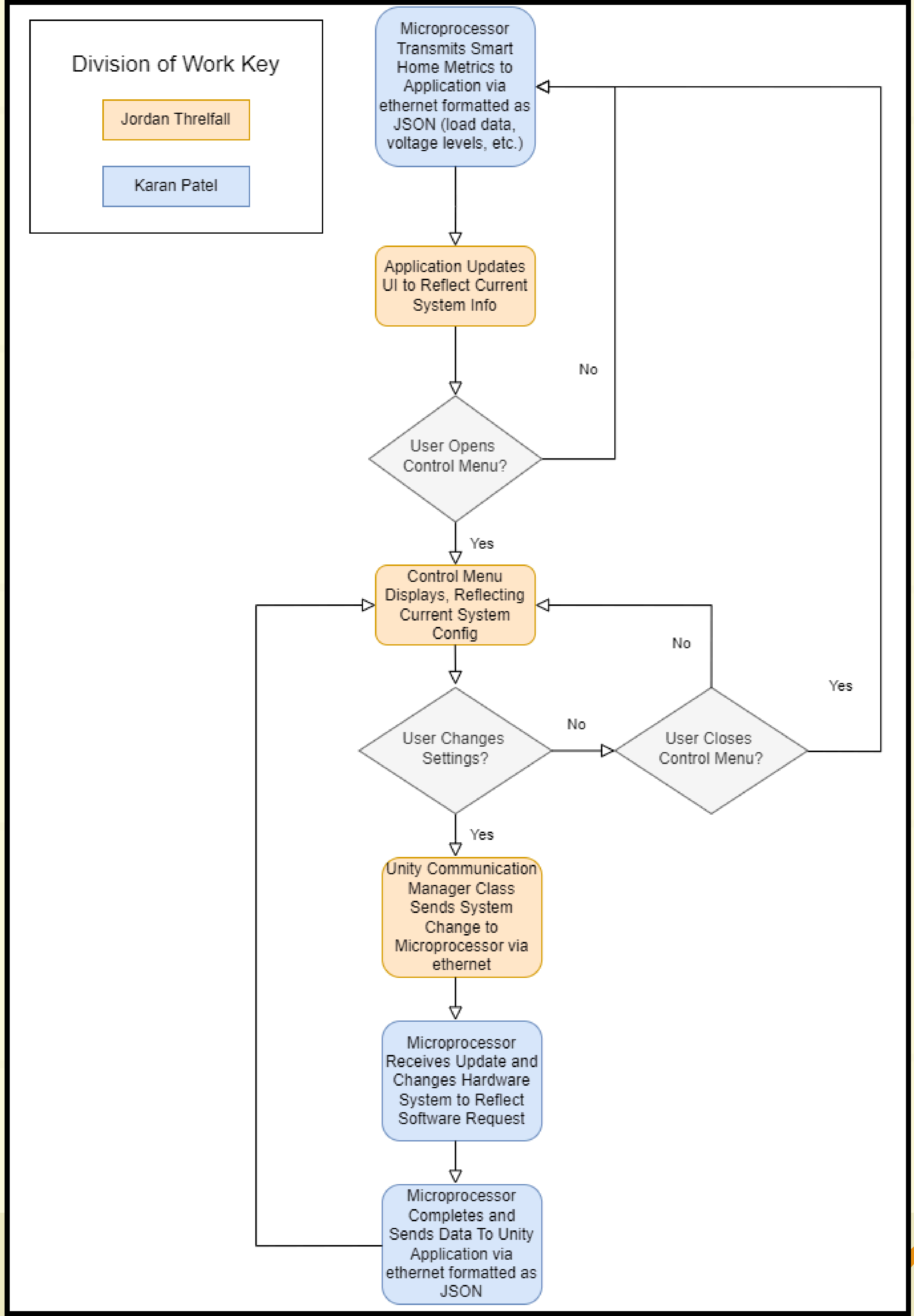
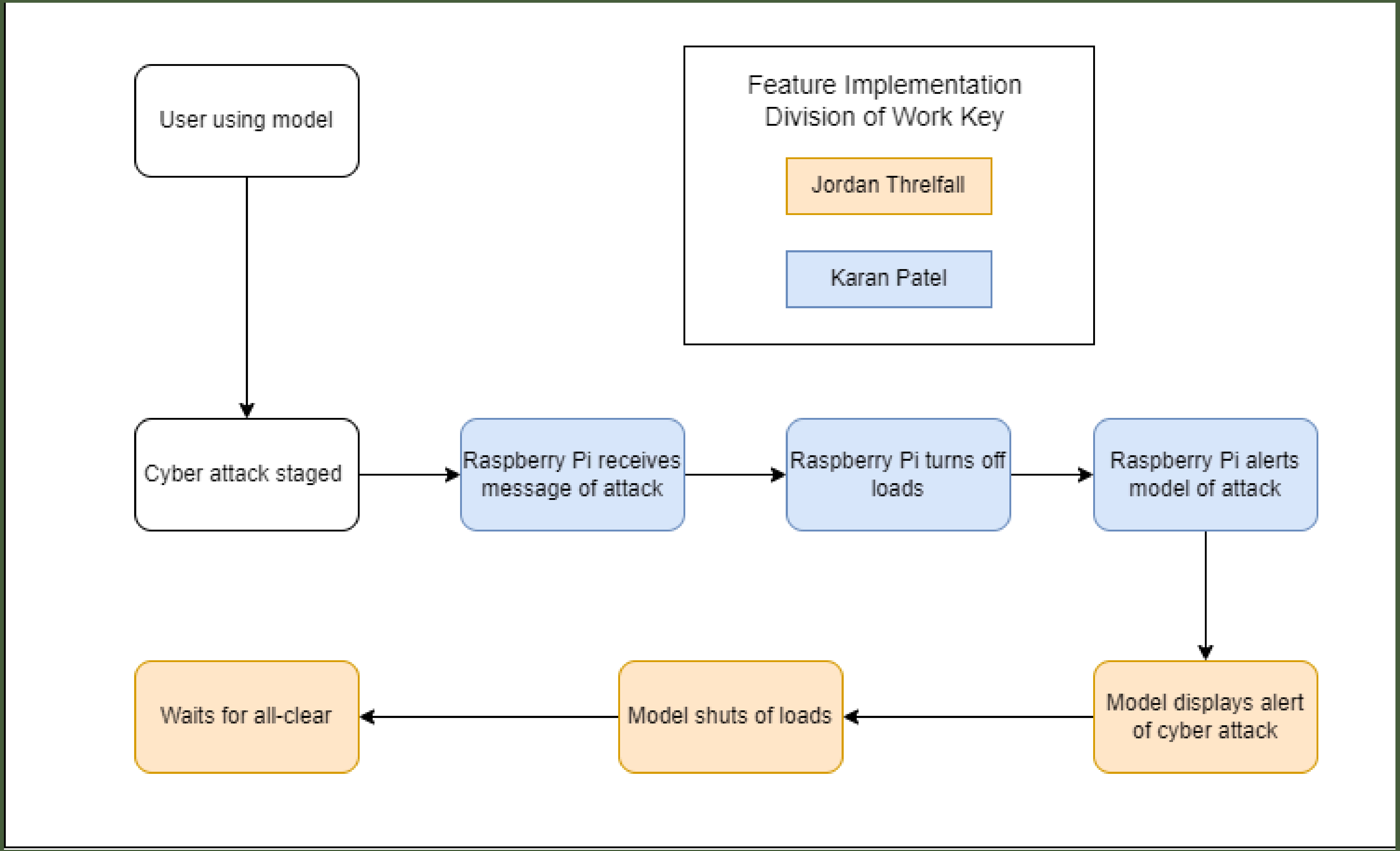
RASPBERRY PI INTEGRATION



SOFTWARE FLOWCHART

CYBER ATTACK EVENT



SELECTION OF SOFTWARE COMPONENTS

UI APPLICATION TECHNOLOGY

Parameters	Game Engine Executable	Web Application
Components	Executable file	Static Page Generator
Language Type	Object Oriented Language	Markup Language
2D or 3D	Both	2D
Languages	C++ OR C#	HTML/CSS OR Node JS
Application Customization	Tools available to implement	Tools need to be created
Cost	Free	Free
Computing Power	Requires more power	Requires less power

For the requirements of this project, we determined that utilizing game engine tools would prove to be incredibly useful in the development of this application. Some of the great benefits include available user interface components, simple application start-up using an executable and the object-orientedness of the program.

SELECTION OF SOFTWARE

UI APPLICATION COMPONENT

Parameters	Unity	Unreal Engine	Godot
Resources / Support	Engine documentation Large community support	Engine documentation Medium community support	Engine documentation Small community Support
Price	Free	Free	Free, Open source
Typical Applications	Simple 2D/3D projects	Complex high resolution graphics	2D/3D projects
Languages	C#	C++	GDScript, C#, C++
Audience	Small team development	Large team development	N/A
Common Uses	Independent developers, Education, Small to medium sized projects	Triple-A titles, High-quality indie games, VR experiences	2D and simple 3D games, hobbyists and independent developers, education

Unity

In the context of this project, we went with Unity, as it offers great tools for creating features and the fact that we are not creating complex applications.

USER INTERFACE

HARDWARE TESTING

HARDWARE SUCCESS

- Connection of PV, Battery, and DC Load to Charge Controller
- Collection of Metering Information from PV & Battery
- Connection of Inverter to Battery; AC Load to Inverter
- Current and Voltage Sensor Testing with Arduino
- Completed Energy Management System and Controlled Relays for Different System States

CHALLENGES

- Collecting Accurate Information from Current Sensor
- Implementing Switching Between Two AC Sources
- Collecting & Sending Metering Information from AC Sources
- PCB Troubleshooting

SOLUTIONS

- Connected Both Outputs of Relay and Toggled Them for Switching Between Two AC Sources
- Utilized Current Transformers to Collect Metering Information from AC Sources
- Continued to Test and Corrected PCB Design

SOFTWARE TESTING

SOFTWARE SUCCESS

- System Config Sent to Raspberry Pi
- UI Views Correctly Displaying Components
- System Hardware Metrics Accurately Displayed on Components
- Correct Handling of Cyber Attacks
- OPAL-RT / Raspberry Pi Communication
- Raspberry Pi Control Over Relays

CHALLENGES

- Correct Information Parsing Between UI App and Rasp Pi
- Networking Challenges

SOLUTIONS

- Validated that strings were correctly constructed
- Validated that both devices are on the network and IP addresses and that ports were correct

BUDGET

Item	Price	Qty	Total Cost	Details
Controller for Solar Panel	$24.99	1	$24.99	Controller
Renogy Monocrystalline Solar Panel	$104.99	1	$104.99	Power Source
Renogy Battery (Sealed)	$189.99	1	$189.99	Power Source
HiLetgo 12V 8 Channel Relay Module	$11.29	1	$11.29	EMS Control
Phillips 55BDL4051T Touchscreen	$1,678.00	1	$1,678.00	User Interface
Renogy Inverter	$119.99	1	$119.99	DC/AC Conversion
Meter (V, I, P)	$14.99	2	$29.98	Metering for AC Source/Load
Meter (V, I, P)	$14.99	3	$44.97	Metering for DC Load
DC Fan	$15.99	1	$15.99	DC Load
AC Lamp	$9.99	1	$9.99	AC Load
Raspberry Pi 4 Model B	$79.49	1	$79.49	EMS and Communication with OPAL-RT / Application
Printed Circuit Board (5)	$108.99	1	$108.99	Used for Metering

WORK DISTRIBUTION

- PV Metering Portion of PCB
- RT Lab Model (OPAL-RT)
- AC/DC Connection Within Model House
- Smart Home Energy Management System
- AC Source Metering

- Battery Metering Portion of PCB
- Relay Connections
- AC/DC Connection Within Model House
- PCB/Rasp. Pi Communication

- Rasp. Pi Communication with OPAL-RT
- Rasp. Pi Control of Relays in Model
- PCB Communication with Rasp. Pi (Metering Info)

- User Interface (UI) App
- Receiving and Sending Messages to UI
- Implementing the Communication with Rasp. Pi and UI

THANK YOU!